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drawings with the admirable series by Mr. BARNARD, which are given in Plates I to IV.

There are three general remarks to be made on these drawings. In the first place, while the general features of the planet's surface have remained about the same from 1875 to 1889, there has been an entire change as to the form and disposition of the details. In the second place, the disposition of color on the surface of the planet has entirely changed, also. In 1889 there is very little of the red color to be seen, except in the great central belt, while in 1875 red belts were seen almost to the poles. Thirdly, the characteristic red color itself has changed in a surprising manner since 1875.

The color of the red markings in 1875 was most carefully matched in crayons, and I was finally satisfied with the tint of the drawings. In 1881 I found that the same crayons (pieces of which I had preserved) would no longer match the red belts. In 1889 the color of the red belts is entirely different from that previously drawn. All the observations were made with CLARK objectives (of 26, 15½ and 36 inches aperture), which had their color-corrections very much alike. Unfortunately, it is not practicable to reproduce these colors in Plate V. The notes follow:

The top of the drawing is south; the right-hand side is east, or following.

1875. June 16, seeing not good; June 18, hazy; June 24, the columnar structure in the southernmost belt is somewhat too coarse; July 13, the position of the shadow of the satellite is for $8^h\ 40^m$; July 16, planet unsteady.

## NOTICES FROM THE LICK OBSERVATORY.

PREPARED BY MEMBERS OF THE STAFF.

### ON THE DETERMINATION OF THE BRIGHTNESS OF STARS BY MEANS OF PHOTOGRAPHY.

Dr. CHARLIER, assistant in the Observatory at Stockholm, has prepared a memoir* on the use of photography in determinations of the brightness of stars, which has been published by the Astronomical Society of Germany, and dedicated to the Pulkowa Observatory, on the occasion of the fiftieth anniversary of its foundation, August 19, 1889.

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* *Ueber die Anwendung der Sternphotographie zu Helligkeitsmessungen der Sterne*, von C. V. L. CHARLIER. *Publication der Astronomischen Gesellschaft*, XIX. Leipzig 1889, 4to. (pp. viii, 31).

The subject treated is so new and so important that it will not be out of place to give a brief review of Dr. CHARLIER's excellent treatise here, and to add some general considerations on the same question. The importance of this subject will be obvious, when we consider that within the next decade we may expect to have at least two sets of photographic maps, covering the whole sky from pole to pole, and including millions of stars down to the fourteenth magnitude.

Besides these systematic maps, hundreds of charts of special regions will be made. Each star on each of these maps will have impressed its image on a negative plate as a disc of measurable size. Hence the magnitude of each and every star *can* be determined if necessary, and when the catalogue of the stars to the eleventh magnitude, also proposed by the Congress, is constructed, the magnitude of each one of these two million stars *must* be given.

There are two imperative questions to be settled before the principles on which this great work is to be done can be considered to be established. The first and more special question is, What is the relation between the diameter of the photographic image of a star ($d$) the aperture and focus of the telescope employed ($a, f$) and the exposure time ($t$), and what is the relation between the (photographic) brightness of a star and the diameter of its image? Having satisfactorily determined the relations just named, the second and more general question presents itself, namely: On what fundamental principles ought the photographic magnitudes of the stars to be assigned?

These two questions are not treated separately in the work before us. Its second paragraph states the problem of the photographic photometry of stars as follows: It is "to determine the function which gives the relation between the size of the photographic image and the photographic brightness of the star, and to determine the constant quantities in this function *in such a manner that the resulting photographic brilliancies shall correspond accurately throughout with the brilliancies determined visually.*"

In my judgment, this is by no means the problem of stellar photographic photometry. It is impossible, in general, to fulfill that portion of the above statement which I have printed in italics. The difference between the photographic and the photometric magnitudes of *Aldebaran*, for example, is more than one and one-half magnitudes, and so with other stars. We may leave this part of the question for the moment, and proceed to give a brief analysis of Dr. CHARLIER'S memoir, laying stress principally on the novel portions of his work.

The observations which he discusses were made with a photographic lens by STEINHEIL of 3.19 inches aperture and 39.37 inches focus ($\frac{f}{a} = 13$). The plates took in an area of twenty square degrees. The images were satisfactory over a field of about three degrees in diameter. Stars to eighth magnitude, inclusive, left trails. The plates employed were made in Lyons, by LUMIÈRE. Four plates are discussed. All were exposed on the *Pleiades*, as follows: No. 2, $t = 13^m$; No. 4, $t = 2^h$; No. 24, $t = 1^h30^m$; No. 26, $t = 3^h$. The plates were exposed at very different altitudes, and no account is taken of absorption of light by the atmosphere.

Dr. CHARLIER finds two defects in the plates: first, bright rings round the larger stars, which he proves to be due to reflections from the back of the plate (the well-known halation images); and, again, false stars. He finds no less than fifty-six such false stars on his plate No. 26. They were probably due to defects in the manufacture of the plate itself.

As subjects for experiments he chose the *Pleiades*, because their photometric magnitudes are accurately determined, and also because they afford a variety of magnitudes within a comparatively small area.

Although he does not expressly mention the fact, the *Pleiades* have the special advantage for his purpose of being all of the same spectral type. A region containing many very red or many very blue stars would have given a corresponding number of anomalous results, which are avoided by choosing a group of stars of one type. The diameter of each star on each of the four plates was measured. Calling $H$ the brightness of a star, and $m$ its magnitude, and 0.4 the light ratio, Dr. CHARLIER starts with the formula

$$(1) \quad . \; . \; . \; . \; . \; . \; . \quad H = (0.4)^m$$

That is, he assumes that the brightness of a first magnitude star ($m = 1$) is 0.4. It is better to write this formula, I think,

$$(2) \quad . \; . \; . \; . \; . \; . \; . \quad H_m = (0.4)^{m-1}$$

which for $m = 1$ gives $H_1 = 1$. Assuming the equation (1), however, and further assuming that when $d$ is zero, $H$ must be zero, he finds

$$(3) \quad . \; . \; . \; . \; . \; . \; . \quad m = a - b \log d$$

Here it may be remarked that, in fact, $H$ is not necessarily zero for $d = o$, because all stars below a certain brightness will fail to produce an image on the plate, no matter how long the exposure may be—for any practical exposure-time. The brightness of a star must be above a certain finite limit in order to produce any impression at all. The assumption is sufficiently accurate, however, for the purpose in hand. The relation between exposure-time and diameter of star image is next determined from a series of exposures on *Polaris*, assuming the form

(4) . . . . . . . $d = d_0 \,.\, t^k$

That is, that the diameter of the star-image varies as the $k^{\text{th}}$ power of the time. From *Polaris* (two plates) the values of $k$ are 0.243 and 0.249; from a star 5th mag. $k$ results 0.243,—hence, the numerical value of the diameter of the star-image varies as the fourth root of the time or

(5) . . . . . . . $d = d_0 \,.\sqrt[4]{t}$

This formula shows that the diameter $d$ will be doubled when the exposure $t$ is increased sixteen-fold.

If there are no limits to the formula it also shows that, for the telescope and plates employed, an exposure of $\frac{1}{16}$ second would give a perceptible image. Without considering the question of the *range of sensitiveness* of plates I may state it as my opinion that the formulæ of Dr. CHARLIER and those of Professor SCHAEBERLE (*Publ. Ast. Soc. Pacific*, No. 4) can (at present) be applied safely only to *over-exposed* stars, and that there is a superior limit also beyond which they are no longer applicable. Both Dr. CHARLIER and Professor SCHAEBERLE have found that the stars with the longest exposure are best fitted for the determination of magnitude.

We may now quote, without further remark, the final formula to which Dr. CHARLIER is led, which gives the relation between $m$ (star's magnitude), $d$ (diameter of star-image on plate), and $t$ (exposure time). It is

(6) . . . . . . . $m = A + B \log d + C \log t$

In the particular plates in question the constants $A$, $B$ and $C$ are

$$A = +\ 17.2 \quad B = -\ 6.75 \quad C = +\ 1.69$$

$A$, $B$ and $C$ are proved to be constant on the four plates in question; $t$ is expressed in minutes.

From the formula (6) the photographic magnitudes of fifty-two of the brighter stars in the *Pleiades* were computed, and compared with the photometric magnitudes of the same stars as determined by Dr. LINDEMANN, at Pulkowa. (Table III.)

The mean difference between the photographic and photometric magnitudes is ± 0.22 mag. The differences occur 0.6 mag. (twice), 0.5 (twice), 0.4 (4 times), 0.3 (12 times), 0.2 (12 times), 0.1 (10 times), 0.0 (7 times). Two stars are either variable or red. The individual results for the photographic magnitudes from the four plates agree well. The mean difference is 0.10 mag. The largest difference is 0.4 (occuring twice).

Dr. CHARLIER makes the important remark that the red stars, etc., which are thus discovered in the group of the *Pleiades*, are very suitable for a determination of its parallax, since they differ in spectral type, and are therefore *presumably* not members of the group. A few moments' examination with a small spectroscope will, however, be a surer indication in similar cases.

Section III of the memoir is devoted to a comparison of the results of the Stockholm photographs with those obtained by Professor PICKERING, at Harvard College, and by Dr. SCHEINER, at Potsdam. The linear formula deduced by the latter is shown to be inferior to the logarithmic form adopted by Dr. CHARLIER; and in Table IX it is shown that the systematic differences between the results at Harvard College and at Stockholm are likely to be due to constant errors in the H. C. O. results. In all this discussion, as has been said, the effect of atmospheric absorption is omitted, as it has been in all previous publications of the kind. It is of considerable amount, however.

Section IV of the memoir is chiefly concerned with a comparison between the photometric magnitudes given by WOLF, of Paris, for 571 of the *Pleiades* stars and the photographic magnitudes of the same stars derived from one plate (only) taken at Stockholm. Twenty-eight of WOLF's stars do not appear on this plate; *en revanche*, it contains more than 100 stars not in WOLF's catalogue. In passing, we may remark that the single Stockholm plate made in three hours has a value at least comparable with the chart of M. WOLF, which was the result of many months of labor. It is worth while to remark here that it is highly desirable for the present to make every result derived by photography depend on two negatives at the very least. A comparison of the scales of WOLF and CHARLIER closes this section and concludes the important work.

We may now say that the present memoir and that of Professor SCHAEBERLE, previously cited, have fixed the form under which discussions of this character must be made in future. For every telescope a relation between the diameter of a star image and the corresponding exposure must be deduced in the form $d = \Phi\ (\log t)$.

The constants of this formula will vary with the aperture, focus, plate, site, and with the spectral type of the star, and will probably be applicable only within certain limits of absolute brightness and within certain limits of exposure time.

The memoir of M. CHARLIER is an excellent example of the method of discussion which must be adopted to determine this function for all cases where the prime object is to make the photographic magnitudes harmonize as nearly as possible with the photometric. The real fundamental question is, however, Should any endeavor be made to harmonize them? I proceed to discuss this point as briefly as possible, in the light of our present knowledge, since it is the most important question remaining open for settlement.

### *Establishment of the Present System of Visual Magnitudes.*

Let us consider, very briefly, the history of the introduction of the present system of visual magnitudes. The main epochs in this history are very few. The first is that of PTOLEMY (A. D. 150,) who arbitrarily assumed the brightest stars to be of the *first*, the faintest which he could see, to be of the *sixth* magnitude. The other stars were divided into classes of 2d, 3d, 4th, 5th, etc., magnitudes. The second great event in this history is the publication of the *Uranometria Nova* by ARGELANDER, in 1843. He adopted the general rules laid down by PTOLEMY, and followed by SUFI, TYCHO and BAYER. The brightest stars were called first magnitude, the faintest visible to the naked eye were called sixth magnitude. Stars of the classes 2, 3, 4, 5, etc., were intermediate. By FECHNER'S law, it necessarily followed that equal differences of sensation corresponded to equal *ratios* of light; or that the light of a star of $m^{\text{th}}$ magnitude must be $\frac{1}{\delta}$th part of the light of a star one magnitude brighter $(m-1)$. Measures of this *light-ratio* $\delta$ show its numerical value to be 0.4 very nearly, omitting all questions of small variations, etc.

The *Durchmusterungen* of ARGELANDER, KRUEGER, SCHOENFELD and THOME will determine the visual magnitude of every star in both hemispheres as bright as the tenth magnitude by this same scale. That is, if the brightness of a star of the first magnitude is unity, the brightness of a star of the $m^{\text{th}}$ magnitude is

(7) . . . . . . . $H_m = (\delta)^{m-1}$ where $\delta = 0.4$

The universal practice of modern observers has extended this scale from the tenth down to the sixteenth or seventeenth magnitude (the faintest stars now visible in the largest telescopes). Thus the *accidental* choice of the sixth magnitude as the limit of the naked-eye stars by PTOLEMY has fixed the light-ratio and the practice of all astronomers with regard to visual magnitudes for all time to come. It is to be noted that if PTOLEMY'S work on visual magnitudes were to be done again *de novo*, and absolutely independently, the method chosen would be essentially the following: *One* standard star would be chosen (*Polaris*, in our hemisphere). This star would be compared with a selected group of stars, and the fact of the constancy (or the law of the variation) of its light during the course of the observations would be established. Every other star would be compared with *Polaris*, either directly or indirectly, and its relative light determined. Some convenient magnitude would be *arbitrarily* assigned to *Polaris*, and some convenient light-ratio would be *arbitrarily* assumed. The magnitude of any and every star would then be deduced from the measured ratio of its brightness to that of *Polaris* by a formula like our (7) in which the numerical value of $\delta$ would be assigned on grounds of convenience alone. It is very likely that the value $\delta = 0.4$ would be again chosen, because the tenth part of a magnitude (easily written with one place of decimals), thus defined, is about the limit of perception of the most highly trained human eye.

Such, I conceive, would be the process adopted if the whole question of visual magnitudes was entirely open, and if a Congress of Astronomers were called in 1890 to decide on the proper methods to be followed in fixing the visual magnitudes of the stars anew, or for the first time. The process is simple, it is complete, it is logical, it is sufficiently accurate for all conceivable uses to which visual magnitudes are to be put. The use of a visual magnitude assigned to a star is chiefly to determine its brightness at one epoch, so that observations at other epochs will determine whether there have or have not been changes in its light. It is from celestial bodies which are subject to change, and chiefly from these, that we can hope to learn anything of the nature of celestial bodies in general. A secondary convenience in having a magnitude assigned to a star is to aid in identifying, classifying and describing it.

### *Establishment of a System for Determining Photographic Magnitudes.*

The International Congress of Astronomers will have to decide the question as to how to define the photographic magnitude of a star. They will soon be in possession of plates on which millions and millions of stars have impressed themselves. The diameter of each one of these stars can be measured. The photographic brightness of each one of these stars relative to the photographic brightness of *Polaris* (for example) can be readily determined. What *magnitude* shall be assigned to each one of these stars? Dr. CHARLIER'S answer to this question has already been given. He would assign to each one of a group of stars a photographic magnitude, deduced on the principle that the mean deviation of their photographic magnitudes from their visual magnitudes should be as small as possible. If the same star occurs in two or more different groups, it will certainly have different magnitudes assigned to it, according as one or the other set of standards is employed. The same method has been followed by Mr. ESPIN and by the Harvard College Observatory in all of its many important publications on this question, notwithstanding the fact that (owing to the color of a star) the photographic and visual magnitudes not infrequently differ by at least *two whole magnitudes.* That is, if the visual brightness be expressed by 1.00, the photographic brightness of the same star may be no more than 0.16, or only one-sixth part. Such anomalies must in the nature of things constantly appear for a considerable percentage of the stars. A tolerable agreement is possible for perhaps eighty per cent. of the larger stars, and even here there will be small persistent differences. For those remaining, the disagreement will be more or less marked, according as the spectral type of the star in question varies more or less from the average type. The reason of this is well known. The eye is sensitive to rays which fall between the FRAUNHOFER lines B and G (approximately) of the solar spectrum. The maximum brilliancy to the eye is somewhere near the line *b*. The photographic plate is sensitive to rays falling between F and N of the solar spectrum (approximately). The plates now in use are sensitive in the highest degree to rays of about the wave length of the line G.

Whenever we have a group of say five hundred stars, whose spectra are nearly all of the same type (as the *Pleiades*, for example,) we can measure for each star the relative energy of the light in the portion of its spectrum between B and G (by the eye), in that between F and N (by the photographic plate), and, *as the energy is distributed accord-*

*ing to the same law in the spectrum of each star of the group*, we can determine constants of reduction which *will* make the photographic magnitudes of the various stars agree well with their visual magnitudes. If, however, two hundred of the stars are very red, one hundred very blue and two hundred of the ordinary type, it is, in the nature of things, impossible to bring the photographic and the visual magnitudes to a good agreement. The very red stars will always appear brighter to the eye than they do on the plate, and the very blue stars will always appear fainter to the eye than on the plate, and there is no process of reduction which will smooth away a difference in their magnitudes which is inherent in their nature. If there were such a process, it would be most unwise to employ it. When I see that a star is of the visual magnitude 1 and the photographic magnitude 2.5, I at once learn something of the nature of this star's spectrum, and so in like cases.

It therefore seems to be a rational and a useful plan to leave out all consideration of the visual magnitudes of stars in determining their photographic magnitudes. A simple and most satisfactory method of procedure would be to assume *Polaris* as the standard star of the whole sky, and to fix its magnitude (when in the zenith of a station at sea level) at 2.00, once for all; to select a set of secondary standards, distributed round the equator, and to determine the brightness of each one of these stars in terms of that of *Polaris* (a proof of the constancy of the light of *Polaris* being thus attained). Important groups like the *Pleiades*, etc., would also have their brightness determined in terms of that of the standard. The brightness of the principal Southern stars should also be fixed in terms of *Polaris* indirectly through the *Pleiades*, etc. A light-ratio should be selected on grounds of convenience alone and the photographic magnitude of every star should be determined by an equation like our equation (7) in terms of a single standard star with a definite light ratio.

If this programme were to be followed, we should simply have to add to our star-catalogues another column headed "Photographic Magnitude," which would immediately follow the column "Visual Magnitude." The agreement or disagreement of the two numbers would tell us something of the nature of the spectrum of each star. In order to have the work exact, it would be necessary that all the stars should be photographed on one kind of plates, as is now done by the Harvard College Observatory, and as will be done by the International Photographic Congress. The photographic Southern

*Durchmusterung* might for convenience have its magnitudes expressed in visual units, though the DM of the Cordoba Observatory will make this unnecessary, and will, in fact, make it distinctly to the advantage of science if the photographic DM is made *entirely* photographic. The International map of two million stars to the eleventh magnitude should, in my judgment, give photographic magnitudes *alone*. I can conceive of no advantage to be gained by determining the approximate visual magnitude of these millions of stars at all comparable with the labor involved. In any event, it would seem that the photographic magnitudes should be given whether the visual magnitudes are or are not.

Such, it appears to me, are the general principles which should govern in the determination of star magnitudes by photography. I have set them forth because no amount of discussion at this stage can be called superfluous. After the International Congress has once settled its methods of procedure, it will be the duty of all co-operating observatories to conform to the spirit and to the letter of the methods finally adopted. As long as they are not yet adopted any suggestions, however simple, cannot fail to be of use.

The Lick Observatory is endeavoring to make a modest contribution to the general subject of which we have spoken. Professor SCHAEBERLE has made observations at Mount Hamilton (4209 feet above sea), and will make observations at Cayenne, South America, (nearly at sea-level), to determine the photographic atmospheric absorption at zenith distances between 0° and 70° or 75°. He has already compared the *Pleiades* and other stars with *Polaris*, and will compare the principal Southern stars with the *Pleiades*, etc. In this way, his observations, if successful, will enable us to transfer the standards of the Northern Hemisphere into the Southern.

The immense work now in progress in both hemispheres under the auspices of the Harvard College Observatory will afford material for a thorough discussion of the whole subject. The contributions of Dr. CHARLIER and Professor SCHAEBERLE have established the final form under which special discussions of this kind must be made. The only part of the subject remaining for settlement is that which relates to the establishment of the fundamental principles on which the final methods of reductions are to be based. I have endeavored, in what precedes, to set forth what seems to me to be a satisfactory system, at once simple and comprehensive. E. S. H.